Last revised: 02/24/93

The Earth Observing System

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The Van Nostrand Reinhold Encyclopedia of Planetary Sciences (1993 Edition)

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INTRODUCTION -- THE MAIN POINT OF THE EARTH OBSERVING SYSTEM

The idea that the climate of Earth has changed is not new. Much evidence has been collected from the sedimentary record indicating periodic as well as secular changes in climate parameters such as surface temperature, precipitation amount, and ice extent and abundance, on many time scales. But in the last quarter of the twentieth century, there are several new elements in the way climate change is perceived. One is the view that human activity is having an impact on climatic conditions, on a global scale. The conclusion of recent studies indicating that anthropogenic chlorofluorocarbons are the root cause of a measured secular decrease in atmospheric ozone column abundance over the Antarctic in spring, illustrates this point (e.g., Solomon 1990). There is other evidence for anthropogenic change on a global scale that may have an impact on climate, such as the measurements of atmospheric carbon dioxide abundance taken at remote locations in Hawaii and Antarctica (Houghton, Jenkins, and Ephrams 1990). These observations show this "greenhouse" gas to have increased in abundance more than 13% between 1962 and 1988, at a rate corresponding to about 0.5%/year since the mid-1970s, though the possible impact on any climate variables remains a debated issue in the scientific literature.

A second new element is the idea that we are capable of measuring globally, over periods of 10 to 20 years, key factors affecting conditions at the surface of Earth, well enough to interpret these observations in terms of changes in the climate of the planet. This idea is based upon the rapid advances in remote sensing instrumentation for aircraft, balloons, and especially for Earth-orbiting satellites. A third idea is that by exerting adequate effort, we can in the next 10 to 20 years develop mathematical models with the ability to predict future climatic conditions on the 10- to 100-year time scale. This view is predicated upon recent advances in computer technology, numerical modeling, and techniques for "assimilating" observational data into climate models.

An international effort is being made to realize the implications of these new ideas. It is taking place under the aegis of the World Climate Research Program (WCRP) and the International Geosphere-Biosphere Program (IGBP). The United States is participating through its multi-agency Global Change Research Program (GCRP). The National Aeronautics and Space Administration's (NASA's) contribution to the GCRP is the Mission to Planet Earth, of which the central element is the Earth Observing System (EOS). According to a recent report, EOS "... is designed to provide comprehensive, long-term observations from space of changes that are occurring on the Earth from natural and human causes so that we can have a sound scientific basis for policy decisions to protect our future" (NASA 1992).

OVERVIEW OF THE EOS PROGRAM

Traditionally, the Earth has been studied by separate scientific communities, each interested in one of five "systems": the lithosphere, the atmosphere, the hydrosphere, the cryosphere, and the biosphere (Earth Systems Sciences Committee 1988). These discipline-oriented research communities have developed measurement and modeling techniques to explore these systems further, and by consensus, have determined which questions became the focus of current research.

Many factors contributed to broadening this view of how research in Earth Science might be accomplished. For example, it was found in the 1970s that the LANDSAT instruments, designed and operated by the community of researchers interested in land processes, also provide information about ocean surface structure and atmospheric cloud behavior. The SEASAT mission focussed on air-sea interactions. It measured such parameters as near-surface wind vector over the ocean, which was used in models of both atmospheric circulation and ocean currents. These studies pointed to possible advantages of "multi-disciplinary" instrument packages. The modeling efforts related to SEASAT also came at a time when improvements in numerical modeling methods and computer hardware made possible the first steps toward coupling atmosphere and ocean climate models, again lowering the barriers between disciplines.

To address the goals of EOS, NASA gave new emphasis to interdisciplinary issues, such as those relating to exchanges of energy, momentum, and material across the interfaces of the systems, and the consequences of these exchanges. "From Pattern to Process" emerged as a slogan that captures the underlying intent of using global-scale data to understand the mechanisms of climate change. New terminology was introduced, such as the concept of biogeochemical cycles, meaning the budgets of chemicals (and their elemental constituents) as they pass through biological and non-biological planetary-scale systems. Over a , these ideas were refined, a process that is continuing with the EOS mission itself. The early history of this effort is documented in a series of reports generated by committees of experts from multiple disciplines (e.g., National Research Council 1986; 1979, and references therein; National Aeronautics and Space Administration 1982; 1983a; 1983b; Earth Systems Sciences Committee 1988; for the related effort involving instrumentation, see Earth Observing System 1991 and references therein).

Seven general areas were identified for their importance to global climate change on Earth, based upon a consideration of scientific, technical, and programmatic factors: tradeoffs between (1) uncertainties in models and (2) what is possible to measure, on what time and space scales, and at what cost (NASA 1992). The intention is to treat each of these subjects in a way that does not stop at the interfaces of the traditional systems.

1. The role of clouds, radiation, water vapor, and precipitation in global climate.
2. The biological productivity of the oceans, their circulation, and air-sea interaction.
3. The sources and sinks of greenhouse gases, and their atmospheric transformations.
4. Changes in land use, land cover, primary productivity, and the water cycle.
5. The role of the polar ice sheets, and sea level.
6. The coupling of ozone chemistry with climate and the biosphere.
7. The role of volcanoes in climate change.

There are three main components of EOS: (1) the EOS Observatories, which are spaceborne platforms carrying instruments that will measure key parameters globally, (2) the EOS Scientific Research Program, which supports the interdisciplinary studies that are required to interpret the data in terms of understanding planetary-scale processes, and (3) the EOS Data and Information System, which must process, validate, document, archive, and distribute the vast amounts of data to be generated by the EOS (and other) instruments and related scientific research efforts. Each of these components is built upon existing parts of the NASA Earth Sciences program. Those elements of the Earth Sciences program identified specifically with EOS are ones that stress global-scale climate issues.

The subsequent sections of this article discuss each of the components of EOS. Plans for these components are being revised, primarily in response to changes in the EOS budget. In 1990, planning for EOS was based upon a projected budget of about $16 billion covering all expenses for the project from the new start in fiscal year (FY) 1991 through the year 2000. By FY 1992, this number had been reduced to $11 billion, and the FY 93 Appropriations Bill placed a funding cap of $8 billion on the project for the same period. These changes forced a narrowing of objectives, and will reduce the flexibility of the program to respond to new insights in the future (Moore and Dozier 1992).

THE EOS OBSERVATORIES

The EOS Observatories are designed to create a database of "comprehensive global observations of Earth." Parameters describing natural forcing of the climate (viz., solar input and surface albedo), natural responses (e.g., temperature, biomass, and cloud cover), and human activity (such as gas emissions, fluid pollutants, and land use patterns), need to be monitored so the cycles of components can be analyzed (see Section 4). The choice of time and space scales for EOS measurements is a critical issue, because of the complexity of the Earth environment and the non-linearity of processes involved (e.g., small causes can have big effects). However, measuring every variable of potential interest to Earth scientists for which an instrument could be built, at the highest resolutions of possible interest, would require an unrealistically large budget, and implies very large amounts of data (see Section 5). Thus, the scope of the EOS database was pared down in several ways.

The time scale for climate changes of interest to this mission is set at 15 years, with 1- to 16-day temporal resolution for variabilities. Regular sampling of key global parameters is to be obtained at spatial scales of 1 to about 100 km, supplemented by local and regional coverage at tens- to hundreds-of-meters for some quantities. The complement of instruments ultimately included on the EOS Observatories was restricted to those that could measure variables believed to address "critical" global change issues within these guidelines (see Section 2). As part of the selection process, instruments which measure slowly changing variables (e.g., rock mineralogy), those which observe parts of the Earth system less likely to impact the biosphere directly (e.g., the magnetosphere), and ones which depend upon major technological advances (e.g., Doppler lidar), were eliminated or deferred. The availability of data from non-EOS satellites and from field studies, including the current and planned programs of foreign space agencies, has also been critical in EOS instrument selection. In spite of the limitations, the EOS Observatories will provide improved spectral resolution, systematically better space-time coverage, and greater coincidence of different types of measurements, than any previous monitoring of Earth. [For detailed descriptions of the instruments selected for EOS, see Earth Observing System, 1991.]

From an earlier strategy for deploying two giant platforms carrying about 15 instruments each, NASA has evolved a plan involving the launch of several series of smaller satellites. Each satellite will operate for about 5 years, after which time it will be replaced by a similar satellite. The several series of EOS observatories will provide 15-year coverage of the Earth. The choice instrument complement for each payload was driven in large part by the desire to minimize the effects of the changing environment when comparing observations from specific groups of instruments.

The first two series of EOS satellites, EOS-AM and EOS-PM, will carry about 5 instruments each, and will observe the Earth from near-polar orbits at altitudes of roughly 700 km above sea level. The first copies of these two observatories, EOS-AM-1 and EOS-PM-1, are scheduled for launch in 1998 and 2000, respectively. The orbits are sun-synchronous; the local time on the surface of the Earth below the EOS-AM satellite will always be about 10:30 AM on the day side (and 10:30 PM on the night side). Cloud cover over land is generally lowest in the morning, making this a good orbit from which to make land surface measurements. For EOS-PM, the corresponding times are 1:30 PM and 1:30 AM, to observe daily heating and cooling cycles and provide coverage complementary to EOS-AM.

The Context of EOS Measurements

The EOS observatories won't observe the Earth alone; many other missions are either already addressing the climatological record of global environmental parameters or will be soon. The longest such records come from the NOAA polar orbiters and the Landsat series satellites. NOAA polar orbiters continue to observe the Earth in two sun-synchronous polar orbits (morning and afternoon), as they have for over 14 years. Each carries an imager for determining the distribution of clouds, surface temperature, vegetation, and snow cover, as wells as infrared and microwave sounders designed primarily to measure the vertical profiles of atmospheric temperature and humidity. Since 1973, the Landsat series has acquired high-resolution, multi-spectral images of Earth, which contain detailed information about land use and vegetation, cloud properties, and surface hydrology.

Over the past 15 years, NASA experiments on several satellites have generated (and continue to generate) long records of atmospheric ozone column abundance (the TOMS instruments), the vertical distribution of aerosols and trace gasses (the SAGE experiments), and the Earth's radiation budget (the Earth Radiation Budget Experiment). Recently NASA launched the Upper Atmosphere Research Satellite (UARS) to measure the chemistry and dynamics of the middle atmosphere, and a satellite to measure ocean currents (TOPEX). In late 1993, the SeaWiFS instrument will begin measuring the biological productivity of the oceans. NASA is cooperating with the Japanese space agency (NASDA) on two missions. The first, ADEOS, will carry a NASA scatterometer to measure the global wind field at the ocean's surface. The Tropical Rain Measuring Mission (TRMM) will measure precipitation in low latitudes at all local times of day (i.e., from a non-sun-synchronous orbit).

The European Space Agency (ESA) and NASDA will launch major Earth-observing missions in the same time period as the first EOS launches. Several other nations have expressed interest in mounting Earth observing missions during this timeframe. Finally, NASA is committed to launching a series of less expensive missions contemporaneous with EOS. Early examples of these "Earth probes" include the TRMM mission, and NASA contributions to the ADEOS mission.

The First EOS Satellites: EOS-AM and EOS-PM

NASA is planning to fly nine instruments on the first EOS-AM and EOS-PM satellites:

MODIS	MODerate-resolution Imaging Spectrometer (EOS-AM and EOS-PM)
CERES	Clouds and Earth's Radiant Energy System (EOS-AM and EOS-PM)
MISR	Multi-angle Imaging Spectro-Radiometer (EOS-AM)
MOPITT	Measurements Of Pollution In The Troposphere (EOS-AM)
ASTER	Advanced Spaceborne Thermal Emission and Reflection radiometer (EOS-AM)
AIRS	Atmospheric InfraRed Sounder (EOS-PM)
AMSU	Advanced Microwave Sounding Unit (EOS-PM)
MHS	Microwave Humidity Sounder (EOS-PM)
MIMR	Multi-frequency Imaging Microwave Radiometer (EOS-PM)

The MODIS and CERES instruments will fly on both satellites; in part, they will contribute to the understanding of atmospheric radiation and clouds. CERES will measure broadband reflected and emitted radiation from the top of the atmosphere at about 20 km spatial resolution, at a variety of angles and several times of day. MODIS will produce broad-swath, multispectral images in the visible and near infrared, at 1 km and 250 m spatial resolutions. MISR, on EOS-AM, will add multi-angle visible imaging of the Earth's surface and aerosols, at 275 m resolution. Together these instruments should help elucidate the complicated relationships between surface properties, clouds, other aerosols, and radiation.

The EOS-PM spacecraft will carry a strong suite of sensors for sounding the lower atmosphere and measuring its interaction with the surface. AIRS, AMSU, and MHS represent major improvements in atmospheric sounding. Taken together, these instruments will produce vertical profiles of temperature and humidity. MIMR, being built by ESA, will contribute global measurements of rain, snow cover, and sea-surface temperature, even in the presence of clouds. By comparing this collection of measurements with cloud, snow, and radiation fields from MODIS and CERES, much may be learned about the Earth's energy budget and hydrological cycle.

A key to understanding the Earth's carbon cycle is measuring how the biomass of land vegetation and oceanic phytoplankton changes. Once again the MODIS instrument takes center stage, with its large number of spectral bands useful for deriving biological information from sunlight scattered by the land surface and upper ocean. The Canadian Space Agency is contributing MOPITT, which will measure vertical profiles of CO abundance and column abundances of methane. With the help of surface properties derived from MODIS, the sources of these two climatically important tropospheric gasses should be identified.

Through multispectral thermal and visible imaging at very high spatial resolution (15 m to 90 m), ASTER will measure many of the quantities needed for understanding the transfer of heat and moisture between the land surface and the atmospheric boundary layer, as well as the thermal properties of volcanoes and their emissions. When combined with MODIS observations, these regional measurements could be expanded to the entire globe.

Other EOS instruments

NASA plans to fly some other instruments, not included on the first EOS-AM and EOS-PM satellites, as part of the EOS program:

LIS	Lightning Imaging Sensor
SAGE-3	Stratospheric Aerosol and Gas Experiment
EOSP	Earth Observing Scanning Polarimeter
ACRIM	Advanced Cavity Radiometer Irradiance Monitor
HIRDLS	HIgh-Resolution Dynamics Limb Sounder
MLS	Microwave Limb Sounder
SOLSTICE-2	SOLar STellar Irradiance Comparison Experiment
TES	Tropospheric Emission Spectrometer
SCAT	SCATterometer
Altimeters	

Several of these instruments should extend the record of stratospheric chemistry begun by the UARS satellite, such as MLS, by measuring abundances for a larger number of chemical species, HIRDLS, by observing the region with much more complete spatial coverage, and SOLSTICE-2, which will continue the measurements of chemically-important UV radiation from the sun. Following the MOPITT instrument, TES is designed to measure the abundance and vertical distribution of gasses in the troposphere, including carbon monoxide, and the greenhouse gas methane.

Measurements of surface winds over ocean and the momentum transfer between the oceans and atmosphere, begun by NSCAT, will be continued by NASA's next SCAT instrument. A laser altimeter is planned, to monitor the shape and thickness of the polar ice sheets, and a follow-on radar altimeter is being sought, to extend the record of ocean topography, from which currents can be deduced. Smaller EOS instruments, which will be flown on satellites of the US or other nations, include a lightening monitor (LIS), two aerosol experiments (SAGE-3 and EOSP), and ACRIM, the next in a series which monitor variations in the "solar constant."

THE EOS SCIENTIFIC RESEARCH PROGRAM

To assure that the EOS data are applied to key interdisciplinary issues, and to help guide the development of instruments and measurement strategies, 29 Interdisciplinary Science (IDS) teams were selected by NASA as part of the program. Twelve of the lead scientists for these teams work at American Universities, 7 are at NASA Centers, and 9 are affiliated with institutions of other nations. A total of 366 researchers were selected as principal- or co-investigators; the median number of members per interdisciplinary science team is 13, with a range from 3 to 25. (For a brief summary of each investigation, see: Earth Observing System 1991.)

The scope, content, and structure of the EOS IDS investigations represents the scientific community's interpretation of earlier efforts to identify "interdisciplinary" issues for global climate change that were discussed in Section 2. Most of the teams cover a wide range of expertise, reflecting the requirements of interdisciplinary work. Each selected investigation encompasses the use of both instrument data (remote-sensing and in-situ) and theoretical models; each is committed to exchanging information with a wider scientific community by contributing specific data products to the ESDIS (see Section 5) and by participating in the EOS Investigator's Working Group (IWG) and its panels.

The IDS investigations can be loosely divided into "process" studies, which concentrate on details of the interactions among Earth systems in particular regions, and global studies. Of the selected US investigations, about 80% have a global focus. Of the international efforts selected by the NASA program, more than 70% are process studies for which the investigators' locations have particular relevance, such as the effects of deforestation and other changes on the Amazon ecosystem (Brazil), the role of terrestrial vegetation in mid- and high-latitude ecosystems (Canada), and the variability in southern ocean productivity due to the El Nino phenomenon (Australia).

Every topic listed in Section 2 is the main focus of at least one IDS study. There are teams refining coupled chemical, dynamical, and radiation models with the aid of assimilated global data, one for each of the stratosphere and mesosphere-thermosphere regions of the atmosphere; six such efforts deal with the global troposphere, with a variety of emphases. Several include work on improving biosphere parameterizations, and one concentrates on the derivation of atmospheric parameters from multiple instruments. There is a study dedicated to the global carbon cycle, one for the global budget of angular momentum, and two on the global budget of water.

Many investigations examine elements of the global cycles in detail. Three studies look at surface-atmosphere exchanges of energy, momentum, and water over oceans, and one each examine specifically the Southern and polar ocean regions. Most of these efforts include ocean productivity as a parameter of study. There is an investigation emphasizing exchanges between the biosphere on land and the atmosphere, one focussed on the water cycle in semi-arid regions, one that will produce estimates of volcanic contributions to the atmosphere, and at least three that estimate runoff (land-hydrosphere exchange), two in mountainous regions. All of these studies involve the collection and analysis of multiple data sets; several include sophisticated models of boundary layer physics and chemistry.

The high priority of the effort to constrain the global hydrologic cycle is also reflected in the IDS investigation dedicated to global cloud physical properties, and several of the global climate efforts place special emphasis on estimating precipitation from observations.

The issue of detecting changes in global climate is addressed in several ways by the IDS program. Two studies have components dealing with long-term climate change (ten thousand year time scales), one making use of high-latitude ice core data, and the other looking at the climatic effects the Andean orogen. Many studies include searches for climate change during the 15 year period of EOS data collection, including focussed efforts by the global carbon cycle and stratosphere groups, several of the global troposphere groups, and at least one group studying mid- and high-latitude oceans.

The principal aim of these efforts is to create better models for predicting the future climate of Earth, to develop what is called "predictive understanding" (NASA 1992). As such, emphasis is placed upon using data to improve models. This involves refining the parameterizations and data assimilation schemes of already-sophisticated atmosphere and ocean models, making basic improvements in models of marine biology and terrestrial ecosystems, and where possible, including global constraints that can be produced by improved budget calculations. But interpretation of the data themselves is in many cases a matter for scientific research. Part of the job of performing this work falls to the instrument science teams, and part will have to be assumed by the IDS investigators and others in the scientific community. The third component of EOS, the Earth Sciences Data and Information System, must make these tasks feasible (NASA 1986). It is to this component that we turn next.

THE EARTH SCIENCES DATA AND INFORMATION SYSTEM (ESDIS)

One implication of the requirement to obtain "comprehensive global observations of Earth" is that a huge volume of data will be involved. A simple calculation illustrates this point: The surface area of the Earth is about 5×10^8 km^2, and the vertical dimension adds about another order of magnitude to the data volume for typical geophysical situations. Relevant temporal scales range from a fraction of a day upward. Sampling on the order of 100 information channels (which are the measurements used to infer geophysical parameters) with about 10 bit encoding is appropriate for most cases. If all measurements were sampled 4 times per day (to resolve diurnal time scales) at kilometer length scales, obtaining global coverage would require more than 10^{13} bits per day. At this rate, the archive would accumulate as much data as is currently stored in all the books in the Library of Congress every few weeks. Even higher spatial and/or temporal resolution is needed to address some of the scientific issues discussed earlier. The overall data volume can be reduced significantly only by resorting to selective spatial and/or temporal sampling.

The sheer volume of data poses serious challenges for the systems that must handle them. Even the "routine" operations that are performed on the data -- reformatting of the raw spacecraft data, radiometric and geometric calibration, geographical registration, conversion to geophysically useful quantities, storage on archival media, cataloging, documenting, and distributing to users, and possibly gridding to create uniform data products -- place unprecedented demands on the storage and throughput capabilities of the data system. The plan is to build upon existing capabilities and experience, creating an ESDIS that will continuously evolve to meet the needs at the time, making maximum possible use of improved technology as it becomes available.

The Structure of ESDIS

Several underlying principles govern the structure of ESDIS (NASA 1986). (1) Since technology is expected to advance considerably over the 15 year nominal lifetime of EOS, the data system is designed in a modular fashion, making it possible to swap individual elements with minimal disruption of the overall system. (2) The ESDIS must serve a geographically widely-distributed community; the system is designed so users can perform as many operations as possible at their home institutions, both for data analysis and for instrument support. (3) Since EOS will produce a relentless stream of data for many years, any pileup at a "slow step" in the ESDIS could be very difficult to correct; as much of the data processing as possible is supposed to be automatic. It is planned that algorithms to produce the initial data products will be running at central sites, so the data can be delivered to users within a few days of acquisition. This raises an issue about steps that fall between routine operations, which can be automated, and aspects of the data processing that require some analysis (see Validation, below). (4) To assure that the data will be handled thoughtfully, an effort is made to locate the main archives at places where there is pre-existing expertise and interest in studying the types of data to be stored there. (5) Since data will be archived in many places, by communities familiar with different formats and content, ESDIS is designed to foster "interoperability." This means that a user can access data from multiple sources from a single interface.

The ESDIS will have many components (Earth Observing System 1991), only some of which are described here. The EOS Operations Center (EOC), located at the NASA Goddard Space Flight Center in Greenbelt, Maryland, is the site of mission control for NASA's EOS spacecraft and their instruments. The Customer Data and Operations System (CDOS) will gather data from the EOS satellites, separate it from the telemetry stream, and deliver it via the NASA Communications network to the EOC and the Distributed Active Archive Centers (DAACs). The DAACs perform a major part of the initial data processing, archiving, and distribution to the user communities. About 100 data products containing geophysical parameters at the resolution of the instruments (called Level 2 data) are to be generated routinely, starting at the beginning of the mission, as well as about 100 gridded and other more highly processed data sets. Over the next few years, large existing data sets from earlier NASA and NOAA missions will be archived and catalogued in these DAACs. Seven existing data repositories are being adapted to the role of DAAC, each covering a unique area of scientific interest:

1. Climate Change, Atmospheric Chemistry, and Biogeochemistry - NASA Goddard Space Flight Center, Greenbelt, Maryland.
2. Land Surfaces -- US Geological Survey's EROS Data Center, Souix Falls, South Dakota.
3. Physical Oceanography -- Jet Propulsion Laboratory, Pasadena, California.
4. Radiation Budget, Clouds and Aerosols, and Tropospheric Chemistry -- NASA Langley Research Center, Hampton, Virginia.
5. Hydrologic Cycle and Hydrodynamics -- NASA Marshall Space Flight Center, Huntsville, Alabama.
6. Cryosphere -- National Oceanographic and Atmospheric Administration's National Snow and Ice Data Center, Boulder, Colorado.
7. Sea Ice, Polar Processes Imagery -- Alaska SAR Facility, Fairbanks, Alaska.

In addition to the data products that will be produced routinely, some data will be acquired only upon request, or in response to special events such as the eruption of a volcano. It is the policy of EOS that data will be available to user communities at the incremental cost of filling a user request, as soon as they are generated.

The Issue of Validation

One of the great challenges of EOS is to make data that is traditionally used by one small community of researchers scientifically meaningful to other communities of researchers who work in different disciplines. How will the meaning of the measured parameters -- the precise definitions, the caveats, and the various types of uncertainties -- be characterized and communicated in a way that is useful to a broad swath of the scientific community? For example, remote sensing measurements of sea surface temperature (SST) sample different horizontal and vertical scales, depending on technique and in some cases on atmospheric conditions. In situ measurements of "the same" parameter have very different sampling characteristics from any of the remote sensing determinations. To the extent that these differences affect the conclusions, any study that uses sea surface temperature derived by one method must take into account the detailed characteristics of the data set used. The need for an accurate description of the scientific meaning of the data is particularly important for climate change studies, which are concerned with long-term records of environmental conditions, and which usually require the simultaneous analysis of more than one measured quantity. "Validation" is the process by which these descriptions are generated.

Validation involves: (1) identifying the assumptions made in deriving a parameter from measured radiances, (2) testing the input data and derived parameter for statistical error, sensitivity, and internal consistency, over the range of conditions under which the parameter is acquired, and (3) comparing with similar parameters obtained from other sources using other techniques. A general methodology for performing these steps has yet to be developed.

Because the handling and use of scientific data for EOS is both quantitatively and qualitatively different from previous experience, NASA initiated the Pathfinder program in 1991. The goal of this effort is to prepare several existing large, geophysical data sets for use by an interdisciplinary community of scientists. If this effort succeeds, it will presage the transformation that the larger Earth Sciences community must undergo to meet the challenges of understanding and predicting global change.

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ACKNOWLEDGEMENT

The work of R. Kahn and D. Wenkert was performed at the Jet Propulsion Laboratory/California Institute of Technology under contract with the National Aeronautics and Space Administration.